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P5 2 Extreme Tea Enthusiasts

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Abstract

Mariana Trench and Mount Everest are homes to the extremes of pressure on Earth and it is well known that pressure alters boiling points of substances. We investigate how significant of an impact this alteration has on the time it takes to prepare three cups of tea. We find that it differs between the two locations by approximately 7 minutes, which shows that even enormous pressure differences would have rather minuscule consequences on our daily activities.

Introduction

Two furthest points from the sea level are the floor of Mariana Trench and the summit of Mount Everest. We will take the descent down to the bottom of Mariana Trench as 11,000 m[1], whereas Mount Everest reaches the height of 8,848.86 m[2], but we will assume it to be 8,800 m, so that the level of accuracy is consistent. These characteristics are the reason behind the locations having, respectively, the greatest and the lowest pressures and the fact that increasing pressure raises the boiling point of substances, and *vice versa*, is a common knowledge. However, we are not aware if this phenomenon affects our lives by any noticeable degree and therefore, we decided to probe the ramification of pressure difference on the time taken to boil water.

Method

The pressure at the bottom of Mariana Trench is the atmospheric pressure at the surface plus the hydrostatic pressure of the ocean, hence:

$$p_1 = p_{atm} + \rho g d \tag{1}$$

where ρ is the water density, g is the gravitational acceleration and d is the depth. Then, the pressure at the top of Mount Everest is just the atmospheric pressure adjusted to the altitude by the barometric formula[3]:

$$p_2 = p_{atm}(1 - \frac{\lambda h}{T_{std}})^{\frac{g\mu}{\lambda R}} \tag{2}$$

where λ is the temperature lapse rate for dry air (0.00976 $\mathrm{Km^{-1}}$), h is the altitude, T_{std} is the standard sea level temperature (288 K), μ is the molar mass of dry air (0.0289 $\mathrm{kgmol^{-1}}$) and R is the gas constant (8.31 $\mathrm{Jmol^{-1}K^{-1}}$).

Knowing the pressures in those locations, we can determine boiling points of water using the ideal gas approximation of the Clausius-Clapeyron equation, given by[4]:

$$\ln\frac{p}{p_{atm}} = \frac{H_w}{R}(\frac{1}{T_0} - \frac{1}{T}) \tag{3}$$

where p is the pressure at which we determine the boiling point T, T_0 is the original boiling point, and H_w is the molar enthalpy of vaporisation of water (40,700 $\mathrm{Jmol^{-1}}$). Rearranging Equation 3 for the boiling point yields:

$$T = (\frac{1}{T_0} - \frac{R}{H_w}\ln\frac{p}{p_{atm}})^{-1} \tag{4}$$

Next, we need to find how much heat is needed to get water boiling and we can achieve this with the heat transfer formula:

$$Q = c_w m \Delta T \tag{5}$$

where c_w is the specific heat capacity of water, m is the mass of the boiled water and ΔT is the difference between the boiling point and the initial water temperature.

Lastly, the boiling time is given from the definition of power as:

$$t = \frac{Q}{P} \tag{6}$$

where P is the power of the kettle used.

Results

Using Equation 1, we determined the pressure at the bottom of Mariana Trench to be 1.1×10^8 Pa; the pressure at the summit of Mount Everest, calculated with Equation 2, was 2.9×10^4 Pa. Substituting these results into Equation 4 yielded boiling points of 796 K and 340 K, for Mariana Trench and Mount Everest respectively.

We assumed use of a regular kettle with 3,000 W of power[5] and took the amount of water needed for three cups of tea as 675 ml[6], which has the mass of about 0.675 kg. Combination of Equations 5 and 6 provided results of how long it takes to boil it, starting from the room temperature of 293 K. These were: 7 minutes and 55 seconds at the bottom of Mariana Trench, and 44 seconds at the top of Mount Everest.

Conclusion

We estimated the difference of the boiling time of water between Mariana Trench and Mount Everest to be over 7 minutes. This result is rather underwhelming, since we would most likely not run out of patience waiting that much longer for our tea, but it served its purpose perfectly. It demonstrates that even the most extreme pressures on Earth would have had a minor influence on our daily activities. However, the dangers of those places mean that drinking tea over there would not become our routine, as it is currently impossible to be experienced with our current technology. Nevertheless, the depths of oceans are an active field of research, which proves to be highly challenging, but also mostly intriguing and worth exploring.

References

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